ASETSDefense '09: Sustainable Surface Engineering for Aerospace and Defense

Denver, CO

August 31-September 3, 2009

U.S. Air Force Reduction of Hexavalent Chromium on Landing Gear Components via Implementation of HVOF Tungsten Carbide Coatings

Presented by: Brad Martin

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **SEP 2009**	2. REPORT TYPE	3. DATES COVERED **00-00-2009 to 00-00-2009**
4. TITLE AND SUBTITLE **U.S. Air Force Reduction of Hexavalent Chromium on Landing Gear Components via Implementation of HVOF Tungsten Carbide Coatings**		5a. CONTRACT NUMBER 5b. GRANT NUMBER 5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)		5d. PROJECT NUMBER 5e. TASK NUMBER 5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Air Force Materiel Command ,Wright-Patterson AFB,OH,45433**		8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)		10. SPONSOR/MONITOR'S ACRONYM(S) 11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**Same as Report (SAR)**	**20**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

Overview

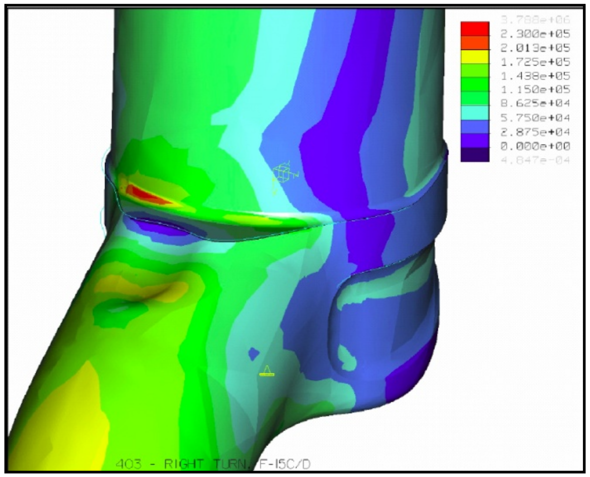
- HVOF Implementation process
- HVOF Implementation progress
- Other engineering services

HVOF Implementation Process

- **All line-of-site Chrome plated high strength steel components are targeted**
- **3-Step Component Approval:**
  - 3D Modeling
  - Stress Analysis
  - System Safety Evaluation (SSE)
- **6-Step Part Conversion:**
  - HVOF Fixture Design
  - HVOF Fixture Fabrication
  - HVOF Spray prototype
  - Grind Prototype
  - Process Order Digital Display System (PODDS)
  - Technical Documentation:
    - Technical Order Update
    - Engineering Change Orders (ECO)

HVOF Implementation Process

- **Step 1 of 3 - 3D Modeling:**
  - Used for component stress analysis (later used for fixture design)
  - Generated from original prints
  - Pro-E or Solidworks
- **Step 2 of 3 - Stress Analysis:**
  - Each component must go through a stress analysis at coating location
  - Performed using limit loads to ensure function under normal stress conditions
  - Not all components identified are suitable for HVOF conversion
    - High stress thin walled (spallation)



HVOF Implementation Process

- **Step 3 of 3 - System Safety Evaluation (SSE):**
  - An SSE must be performed on each component
    - Formal review of safety related changes to original part configuration
  - Separated into two separate cases:
    - General case SSE:
      - Limit stress are below material yield or 226 KSI and at least one of the following:
      - HVOF and EHC finished thickness are equal
      - HVOF is replacing an existing flame spray repair
      - HVOF is specified by the OEM
    - Special case SSE:
      - All others not defined by the General case

OFFICIAL USE ONLY

HVOF IMPLEMENTATION

GROUP 1

GENERAL PURPOSE (DIRECT CHROME REPLACEMENT WITH HVOF) SYSTEM SAFETY EVALUATION (SSE)

REGARDING THE USE OF HVOF COATINGS ON GENERAL LANDING GEAR COMPONENTS

REVISION A

DISTRIBUTION STATEMENT D. Distribution authorized to the Department of Defense and U.S. DoD contractors only (Operational Use), July 2005. Other requests shall be referred to 417 SCMS/GUEB, Landing Gear Engineering, Hill AFB, Utah.

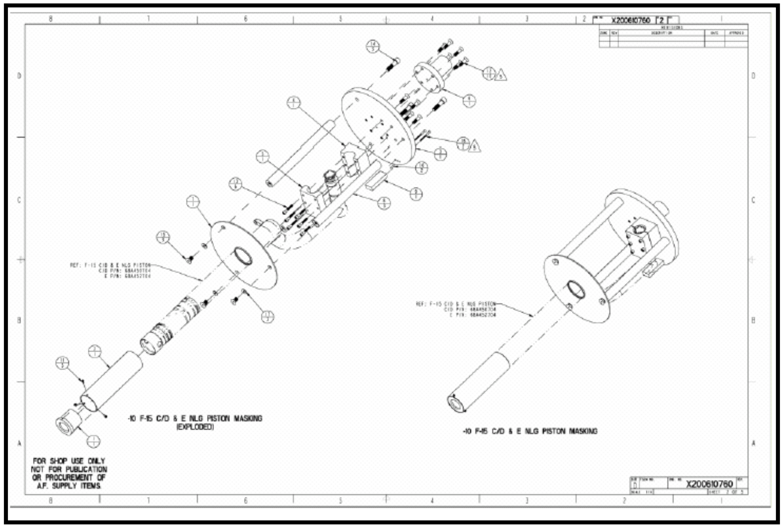
Prepared by: ES3 Inc.
Phone: (801) 698-7939
POC: Richard Vander Straten
Prepared for OPR: 417 SCMS/GUEB

Reference: MIL-STD-882D Standard Practice For System Safety

OFFICIAL USE ONLY

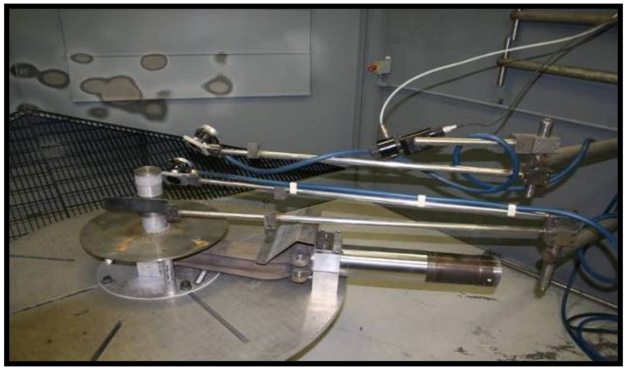
HVOF Implementation Process

- **Step 1 of 6 - HVOF Fixture Design:**
  - Uses previously generated 3D model
  - Fixtures are designed with consideration of booth(s) to be used including:
    - Movement restrictions and limitations.
    - Cost effective manufacturing methods
    - Ease of overspray stripping
    - Ease of operator use
- **Step 2 of 6 - HVOF Fixture Fabrication:**
  - Fixture validation:
    - Dimensional inspection
    - Fit check on actual component
  - Fixture delivery:
    - Custom container including all hardware, fixture blueprints, tolerance stack and run out sheets
    - Recommended spare parts lists
    - Instruction manual



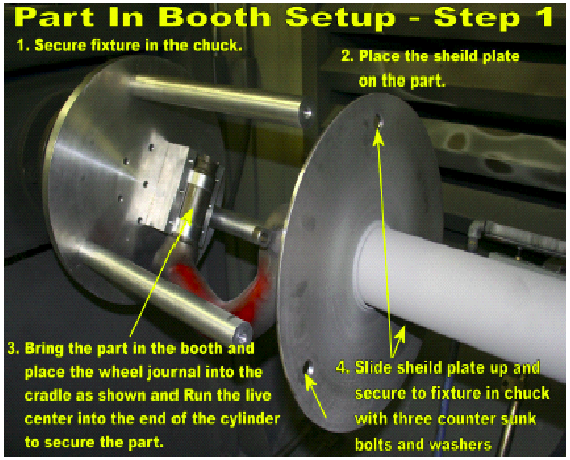
HVOF Implementation Process

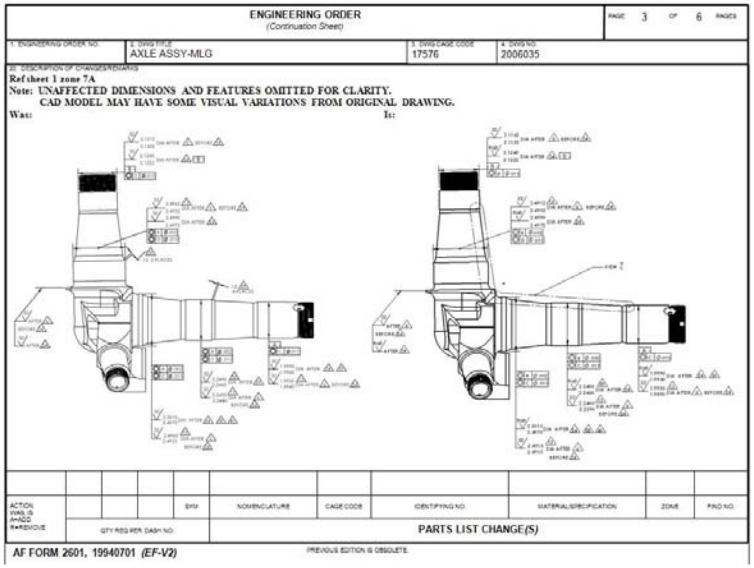
- **Step 3 of 6 - HVOF Spray Prototype:**
  - Prototyping ensures:
    - Application program incorporates all optimized coating methods
    - Ensures part cooling cycles are correct
    - Verifies actual part processing times
    - Verifies tolerances
- **Step 4 of 6 - HVOF Grind Prototype:**
  - Prototyped component is diamond ground
  - Ensures final dimensional and surface finish attributes are achievable within optimized grinding parameters
  - Grinding accomplished per Air Force drawing 200310642



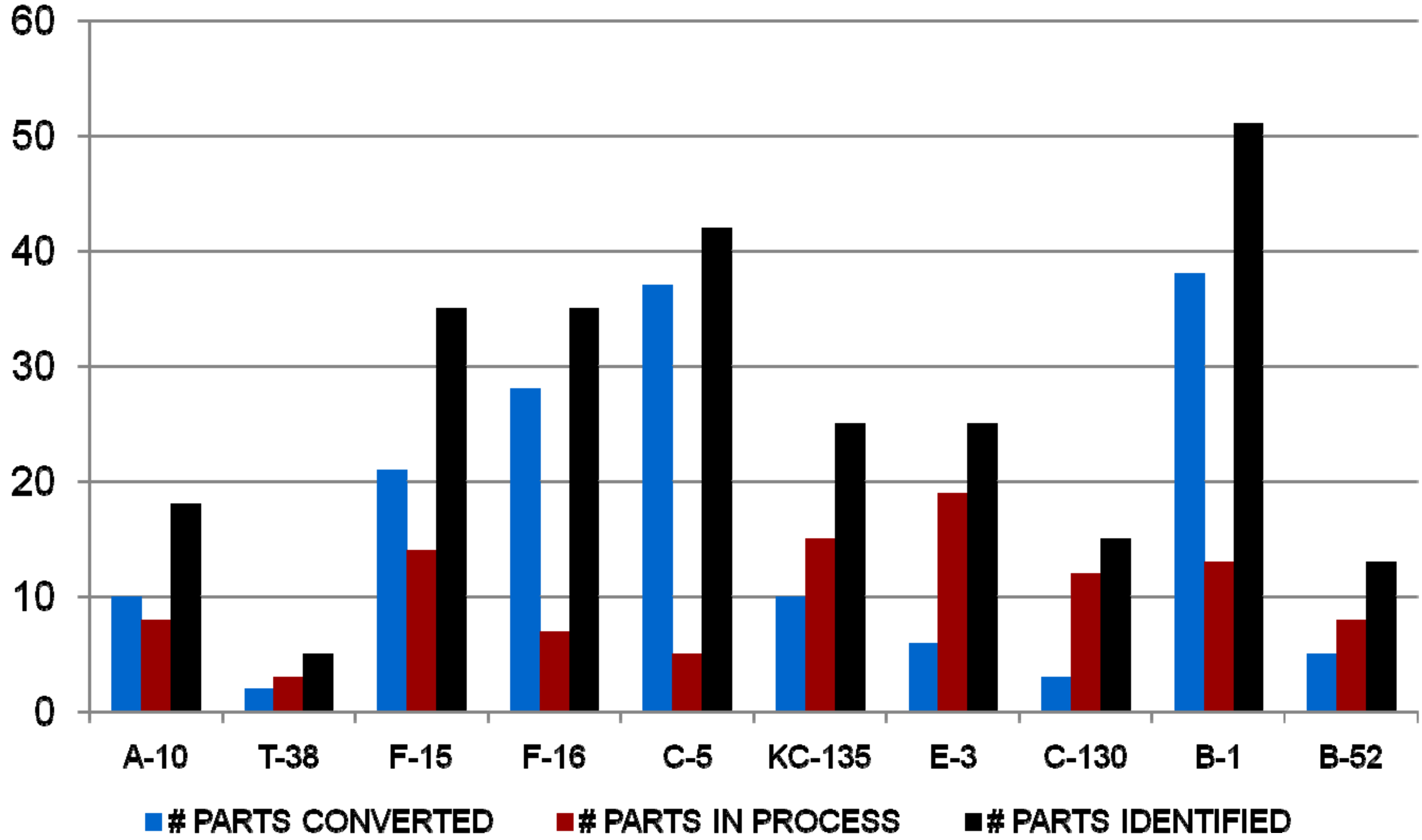
HVOF Implementation Process

- **Step 5 of 6 - Process Order Digital Display System (PODDS):**
  - Process Orders are the detailed, step-by-step instructions for operators to use to ensure process repeatability
  - The digital instruction database is available on line for all operators
- **Step 6 of 6 – Technical Documentation:**
  - Technical Orders updated
  - Engineering Change Orders:
    - Ensures new procurement using HVOF WC/Co in lieu of EHC
    - Converting components ensures future use of EHC will be reduced, thus lowering hexavalent chrome volume and related exposure issues





HVOF Implementation Progress



Other Engineering Services

- **Duplex Coating**

- **Finishing Methods:**
  - Diamond Grinding
  - Superfinishing
  - Diamond Belt Finishing

- **Stripping Methods:**
  - Rochelle Salt
  - Pulsed Water Jet

- **WC/Co Alternatives**

- **WC/Co & WC/Co/Cr Qualification**

Duplex Coating

- **Duplex Coating:**
  - The optimized HVOF WC/Co coatings are currently limited to 0.003”-0.015”
  - Coatings thicker than 0.015” are periodically needed
  - Duplex coating enables application up to 0.030” while maintaining all mechanical properties
  - Phase I complete and working on Phase II

Table 5: Experiment Design Candidates Summary

Experiment Design Characteristics	Experiment Design Candidates: Replicated Mixed 5-Factor Full Factorial	Replicated 5X 4-Factor Full Factorial	Replicated 5X 4-Factor Half Fraction Factorial	5X 4-Factor Central Composite
Powder Types studied	4	4	4	4
Runs	128	136	72	124
Included replications	2	2	2	1*
Detect/quantify linear first-order effects?	Y	Y	Y	Y
Highest order interactions able to detect/quantify	4	4	3	4
Detect system curvature (non-linearity)?	N	Y	Y	Y
Quantify/model system curvature?	N	N	N	Y
Quantify inherent system variation/repeatability?	Y	Y	Y	Y
Generate mathematical system model?	Y	Y	Y	Y
Predict multi-output optimal response?	Y	Y	Y	Y
DOE mitigates influence of unknown extraneous factors?	Y	N	N	N
Study-length control of extraneous factors required?	N	Y	Y	Y
Total change-over time (minutes)	1,920	72	72	72

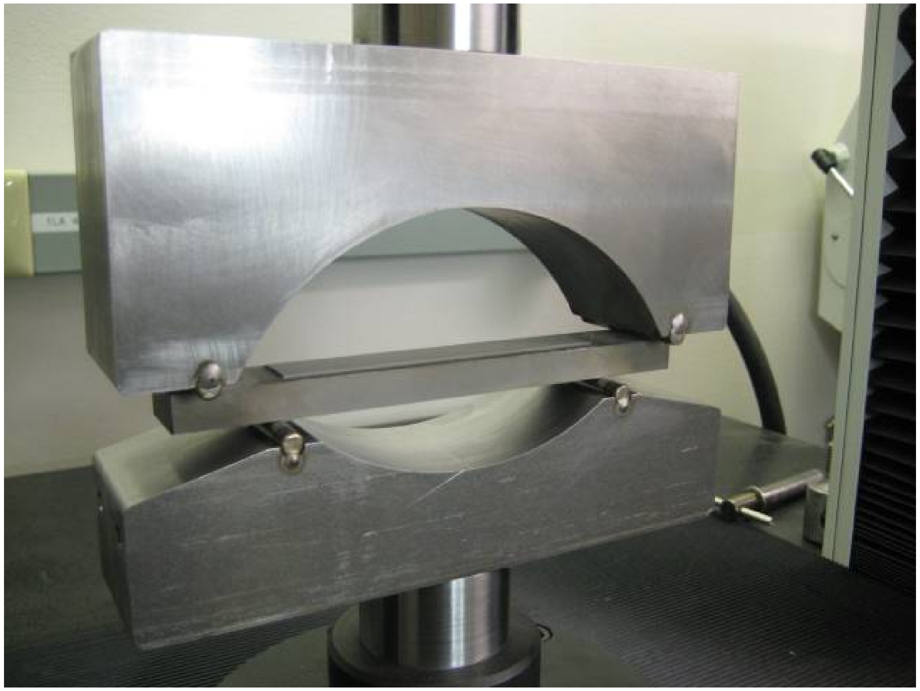
* No replicates on corner and axial points. Multiple replicates, however, placed on center point.

Duplex Coating (Phase I)

- **Phase I:**
  - Identified initial group of coating chemistries
  - Tested per Air Force drawing 200310641
  - Down-selected to 4 chemistries
  - Generated a coating model tool using a Design of Experiment (DOE) method
    - DOE input parameters:
      - Oxygen Flow Rate
      - Fuel Flow Rate
      - Powder Flow Rate
      - Stand-off Distance
  - Coating model tool predicts coating bond strength, ductility, porosity and hardness given changes in the input variables
    - Significantly reduces Phase II testing

Duplex Coating (Phase II)

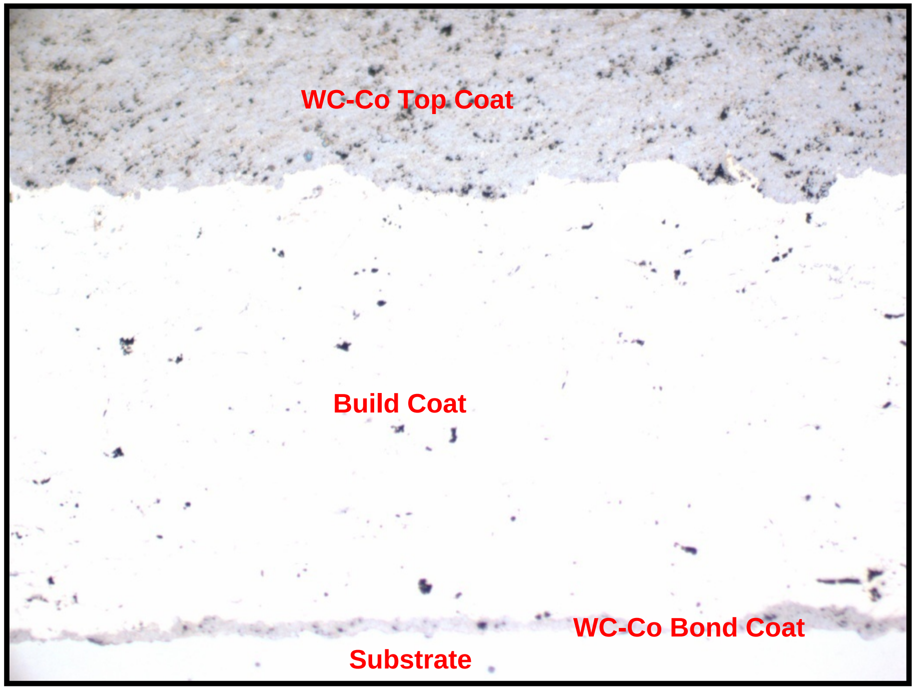
- **Phase II:**
  - 4-point bend integrity testing:
    - 0.020” and 0.030” total coating thickness with 0.003” inch WC-Co cap
    - 0.017” and 0.027” total coating thickness without WC-Co cap
    - 5 cycles at 190ksi, 210ksi and 230ksi stress levels or until failure (spallation)
  - Corrosion testing of duplex system to chrome and WC-Co
    - Per ASTM B117
  - Coating integrity (large bar) testing of 2 best chemistries



4-Point Bend Integrity Testing

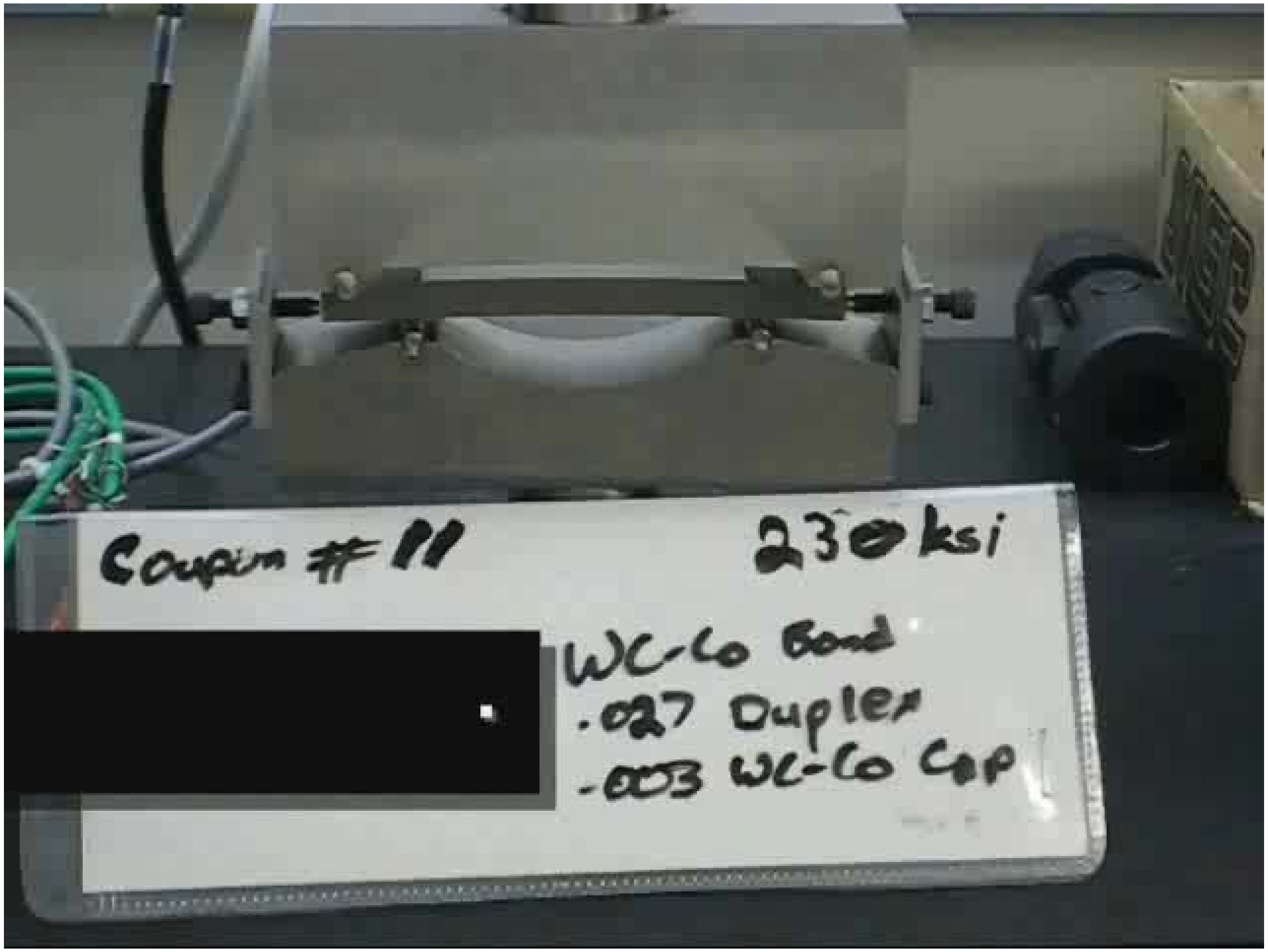
Duplex Coating (Phase II)

- **Phase II Coating Integrity Testing Results:**
  - The optimized build coat performed worse than expected
  - Adding WC-Co cap to build coat failed coupons at lower than predicted stress levels
  - Important observations:
    - The bond strength of WC-Co to build coat was very high
    - The bond strength of build coat to substrate was low
    - Possibly WC-Co bond coat followed by build coat could improve overall bond
  - Integrity testing with WC-Co bond coat:
    - Much better results (at 230 ksi):
      - **No spallation** at 0.027 without WC-Co top coat
      - **No spallation** at 0.030 from 3 of 4 chemistries with WC-Co top coat



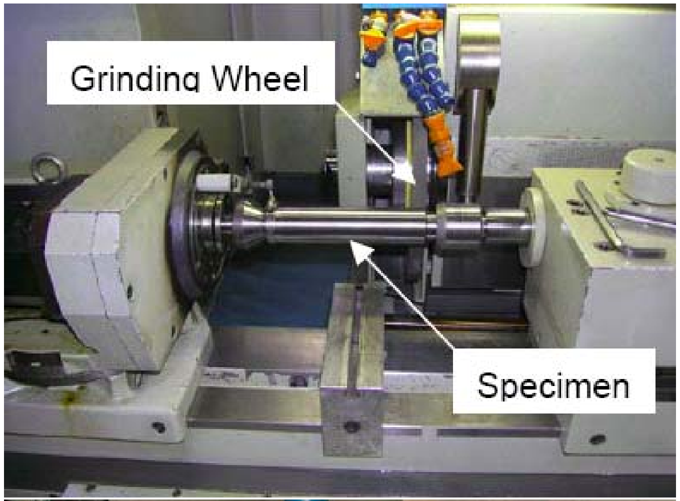
Duplex Coating
(Phase II)

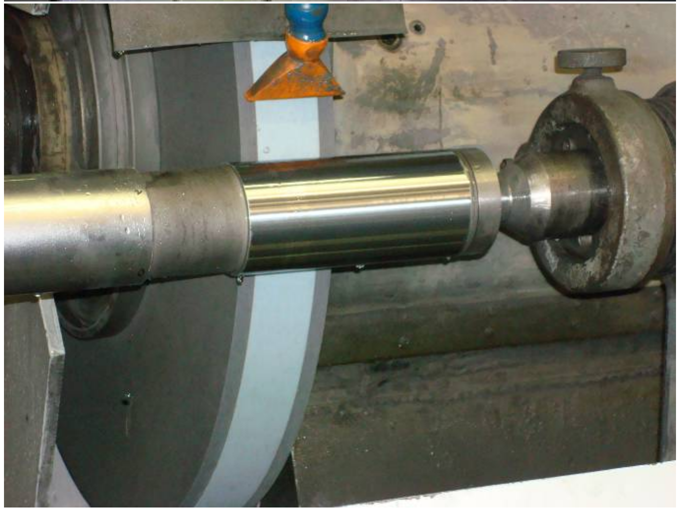
WC/Co Bond-0.027 Build-0.003 WC/Co Top @ 230 ksi



Finishing Methods

- **Diamond Grinding of 300M:**
  - Air Force drawing 200310642:
    - Cylindrical, Face (contoured) and Surface grinding techniques were optimized to reduce/eliminate grinding burns
- **Superfinishing:**
  - Seal surfaces containing HVOF applied WC/Co coatings must be Superfinished after diamond grinding has been completed
  - Superfinishing methods were optimized and written into AF Drawing 200310642
- **Diamond Belt Finishing:**
  - The initial results of testing indicate an increase of processing efficiency by 3-5 times over standard diamond wheel grinding
  - HAFB long bed grinder has been retrofitted with belt attachment
  - Optimization testing will begin this year, specification to follow.

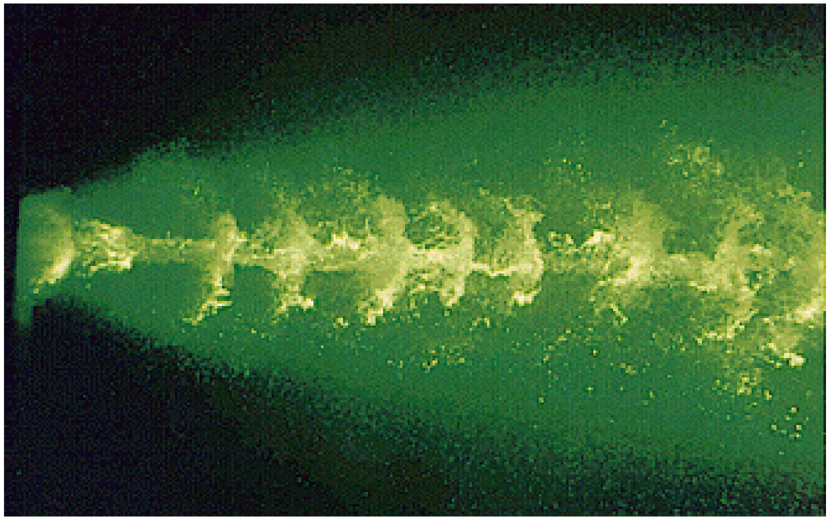




Stripping Methods

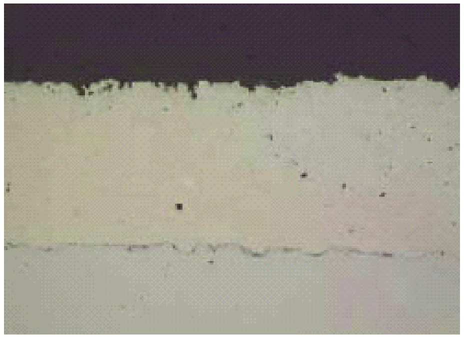
- **Rochelle Salt Stripping:**
  - Industry standard for removing HVOF applied WC/Co materials
  - Electrolytic method under controlled temperature and ph to break down the binder (Co) in the HVOF applied coating
  - Parameters identified within Air Force HVOF application specification-200310641

- **Forced Pulse Water Jet:**
  - Optimized for HVOF WC/Co and WC/Co/ stripping
  - Environmentally friendly
  - Fast, very efficient



WC-Co Alternatives

- **WC/Co Alternatives:**
  - Currently, HVOF WC/Co & WC/Co/Cr is the only approved Landing Gear coating
  - These coating are expensive and have fatigue and spallation concerns
  - It is desirable to qualify alternative coatings which provide:
    - As good as or better than chrome performance characteristics
    - More cost effective
    - Conventionally finished
  - Landing Gear Thermal Spray Specification
    - Requirements which will enable the Air Force to qualify other thermal spray chemistries
    - Modeled after the Landing Gear HCAT JTP



WC/Co & WC/Co/Cr Qualification

- **WC/Co & WC/Co/Cr Qualification:**
  - Enables the USAF to qualify vendors for HVOF WC application on OEM components
  - Qualification based on coatings passing standard metallurgical and performance baselines
  - Specification completed and signed off on 28 July 2009 (200925098)
  - Located at www.fbo.gov

APPLICATION		REVISIONS			
NEXT ASSY	USED ON	REV	DESCRIPTION	DATE	APPROVED
∽	AF ACFT LDG				

REV
DWG NO. 200925098

DISTRIBUTION STATEMENT D:
DISTRIBUTION AUTHORIZED TO DEPARTMENT OF DEFENSE AND U.S. DoD CONTRACTORS ONLY; CRITICAL TECHNOLOGY. 2009-05-22.REFER OTHER REQUESTS FOR THIS DOCUMENT TO OO-ALC/417 SCMS/GUEB, HILL AFB, UT 84056.

WARNING:
THIS DOCUMENT CONTAINS TECHNICAL DATA WHOSE EXPORT IS RESTRICTED BY THE ARMS EXPORT CONTROL ACT (TITLE 22, U.S.C. 2751 ET SEQ.) OR THE EXPORT ADMINISTRATION ACT OF 1979, AS AMENDED, TITLE 50, U.S.C. APP. 2401, ET SEQ. VIOLATION OF THESE EXPORT-CONTROL LAWS IS SUBJECT TO SEVERE CRIMINAL PENALTIES. DISSEMINATION OF THIS DOCUMENT IS CONTROLLED UNDER DoD DIRECTIVE 5230.25.

DESTRUCTION NOTICE:
DESTROY BY ANY METHOD THAT WILL PREVENT DISCLOSURE OF CONTENTS OR RECONSTRUCTION OF THE DOCUMENT

REV STATUS OF SHEETS	REV	-	-	-	-	-	-	-														
	SHEET	22	23	24	25	26	27	28														
	REV	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	SHEET	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21

UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES	DFTSMN 510 CBSS/GBHAC RODNEY GOULD	DATE 09/05/18	U.S. AIR FORCE
TOLERANCE ON: FRACTIONS DECIMALS ANGLES ± ∽ .XX± ∽ ± ∽ .XXX± ∽	CHECKER 510 CBSS/GBHAC BEN DUNKLEY	09/07/17	TITLE Qualification Requirements for High Velocity Oxygen Fuel WC-Co, WC-Co-Cr Coatings On High Strength Steel Substrate (>180 KSI) Landing Gear Components
	MATL ENGR 809MXSS/MXDEA WELDON BETTS	09/07/17	
	PROJ ENGR 417 SCMS/GUEB BRAD MARTIN	15JUL09	
	PROJECT AUTH 417 SCMS/GUEB RON MONTGOMERY	15JUL09	SIZE A · CAGE CODE 98747 · DWG NO. 200925098 · REV
CURRENT CAGE CODE	RELEASE 510 CBSS/GBHAC RICK HARRISON	090723	SCALE NONE · SHEET 1 of 28

Conclusion

- **Benefits:**
  - Improved wear performance
  - Removing a known embrittling process
  - Component longevity
  - Reduction in hexavalent chrome waste stream
  - Greatly reduced rework
  - Faster processing of parts

- **Issues:**
  - Solid infrastructure for EHC
  - Momentum change